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Alternative Fuel Mixture Waste Cooking Oil (WCO) and Corn Oil: Transforming Hazard into Renewable Energy

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ABSTRACT

This study investigated the potential of an alternative fuel mixture comprised of Waste Cooking Oil (WCO) and Corn Oil to convert hazardous waste into a renewable energy source. Converting WCO into renewable energy had the potential to enhance energy security and reduce dependence on increasingly expensive hydrocarbon fuels, which were rising in price. The research conducted a comprehensive analysis of the effects of blending WCO biodiesel with corn oil on engine performance and emissions. The research methodology included two primary components: the transesterification process for biodiesel production and experimental test of biodiesel in diesel engines to evaluate performance and emissions. Data collected during engine operation, such as wattage, RPM, electric current, voltage, time duration, and fuel consumption, were used to calculate torque, specific fuel consumption, and engine thermal efficiency. Additionally, emissions tests were carried out, with a focus on variations in biodiesel samples. The research findings revealed that biodiesel samples containing 50% WCO (B50) exhibited significantly improved specific fuel consumption (SFC) at 678.1 g/kWh, compared to pure diesel (B0) at 852.4 g/kWh, resulting in a saving of 175.3 g/kWh. Furthermore, B50 demonstrated a higher torque output, measuring 3.69 N.m, compared to 3.35 N.m for B0, indicating a 0.34 N.m increase in torque for B50. Moreover, B50 achieved a thermal efficiency 22% higher than that of B0, reaching 22% compared to 20%. In terms of exhaust emissions, B50 displayed a significantly lower concentration (N) of 50.5% compared to B0, which recorded an (N) Value of 98.3%. this research provides valuable insights into the utilization of WCO waste for biodiesel production, offering an environmentally friendly alternative that matches or even surpasses the performance of traditional hydrocarbon fuels. It underscores the potential of WCO and corn oil blends as a sustainable energy source, with notable benefits in efficiency and emissions reduction.

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1. Introduction

The deepening global energy crisis and increasingly pronounced climate change have become critical challenges for humanity in the 21st century. Limited fossil energy resources and the increasingly concerning greenhouse effect drive the need for fundamental changes in the way we produce and consume energy [1]. A global carbon tax is one of the measures being offered but is expected to pose challenges for humans [2]. The most realistic solution is the use of renewable fuels. In this context, biodiesel has emerged as one of the promising solutions to overcome this challenge. Various alternative sources of biodiesel have been tested, with algae being one example. Research has shown that biofuel derived from microalgae can achieve the highest performance in an Organic Rankine Cycle (ORC) system, with the lowest biofuel mass flow rate compared to hydrocarbon fuels [3]. The main focus of world development today is reducing emissions so that biodiesel, as an environmentally friendly alternative fuel, offers great potential to reduce dependence on increasingly scarce fossil fuels and reduce greenhouse gas emissions [4]. Biodiesel, particularly derived from palm oil, offers numerous advantages. However, practical observations reveal a slight reduction in engine power due to its lower energy content compared to hydrocarbon-based fuels [5]. The advantages of biodiesel are particularly notable in its emission reduction levels. A study was conducted by testing palm oil-derived biodiesel on a Toyota Hilux KUN 25 model, yielding results that showed a significant reduction in emissions, especially CO_2. However, this also resulted in a 30% decrease in engine power and an increase in fuel consumption [6]. in an effort to achieve more sustainable energy sources, the focus of research and industry has shifted to Waste Cooking Oil (WCO) or using frying oil, as well as corn oil, as potential raw materials for biodiesel [7,8]. The used of WCO as biodiesel fuel is attracting attention for two main reasons. First, WCO is waste produced from the food and restaurant industry which, if disposed of in an environmentally unfriendly manner, will have a negative impact on the environment [9]. WCO or oil left over from frying food, is used continuously in processing food, will have a negative impact on health [10]. By converting WCO into biodiesel, we can reduce environmental pollution caused by the disposal of this dangerous waste. Apart from that, the use of WCO also helps reduce dependence on petroleum resources which are increasingly scarce and expensive [11].

Corn oil, as one of the abundant varieties of vegetable oils, holds significant promise for sustainable biodiesel production [12]. Sharing akin characteristics with other vegetable oils, the utilization of corn oil in biodiesel production can alleviate stress on natural resources and mitigate greenhouse gas emissions [13]. A study on testing B30 corn oil biodiesel to determine performance values, particularly torque and thermal efficiency, has been conducted. The results indicate that the engine torque using B30 corn oil is lower compared to when the engine uses hydrocarbon fuel. The maximum thermal efficiency achieved was only 17.4%, which is lower than that of hydrocarbon fuel [14]. Nonetheless, despite the considerable potential associated with the utilization of Waste Cooking Oil (WCO) and corn oil as biodiesel feedstocks, several formidable challenges must be surmounted to materialize these prospects. Technical intricacies associated with biodiesel production from WCO are multifaceted, encompassing issues linked to the heterogeneous chemical properties and varying quality of WCO, which can exert pronounced effects on the transesterification process [15]. In the biodiesel production process, transesterification stands as a pivotal method utilized to convert vegetable oil. Employing a catalyst, this method facilitates the transformation of vegetable oil into biodiesel [16]. The application of transesterification is hindered when the chosen oil raw material exhibits elevated levels of free fatty acids (FFA) [17]. Moreover, the selection of appropriate catalysts and the development of efficient purification methodologies present formidable technical hurdles [18]. In the case of corn oil utilization as a biodiesel feedstock, challenges persist, notably those pertaining to the oxidation stability of corn oil [19].

Beyond the technical and economic challenges, divergent regulations governing biodiesel usage across different countries pose a formidable obstacle to the advancement of WCO and corn oil-based biodiesel. Each nation maintains distinct standards and requisites concerning the quality and specifications of biodiesel, alongside varying taxation and fiscal incentives [20]. In the context of these multifaceted challenges and opportunities, an imperative lies in gaining comprehensive insights into the latest research endeavors pertaining to the utilization of WCO and corn oil as biodiesel feedstocks. In the course of this scholarly exploration, we shall delve into the most recent discoveries concerning the impacts of utilizing biodiesel derived from these two raw materials on fuel properties, engine performance, and resultant emissions. Through an enhanced understanding of the intricacies encompassing these challenges and opportunities, we aspire to contribute positively to the development of sustainable biodiesel alternatives capable of mitigating the adverse ramifications of climate change and the global energy crisis.

2. Methodology

In the present study, our primary focus centers on the conversion of two distinct types of vegetable oils, namely waste cooking oil (WCO) and corn oil, into pure biodiesel (B100). Additionally, we explore the blending of these biodiesel variants with pure diesel fuel to create a B50 mixture. The overarching goal of this endeavor is twofold: first, to address the issue of waste disposal associated with used household frying oil, specifically palm oil, and second, to harness the widespread availability of corn oil as a potential resource for biodiesel production within the market. The WCO used in this study was sourced from domestic kitchens, originating from palm oil used in frying pans, while the corn oil utilized was freshly acquired from commercial sources.

The diversification of raw materials, i.e., palm-derived WCO and commercial corn oil, offers a spectrum of compositions in the resulting biodiesel products. To achieve this conversion, we adopted the transesterification method as the central technique, a methodology well-documented for its effectiveness in prior research endeavors within the realm of biodiesel production [21,22]. Extensive literature supports the practicality of this approach in the context of biodiesel manufacturing. The transesterification process hinges on the use of methanol as the alcohol of choice, which initiates a chemical reaction with the triglycerides present in both corn oil and WCO, ultimately yielding methyl or ethyl esters—the fundamental constituents of biodiesel.

To expedite the transesterification process, the introduction of a base catalyst is imperative. In our study, sodium hydroxide (NaOH) serves as the catalyst, assuming a pivotal role in activating triglyceride molecules, facilitating their interaction with methanol, and thereby facilitating biodiesel production [23]. Following the completion of the biodiesel synthesis process, the subsequent step involves a battery of tests aimed at assessing the physical and chemical attributes of the biodiesel products. These comprehensive property tests encompass viscosity, density, flash point, and other key parameters, ensuring that the biodiesel meets the stringent quality standards mandated for such products.

For a more detailed elucidation of the biodiesel manufacturing process, please refer to Figure 1, which provides a visual representation of the sequential stages involved in this study.

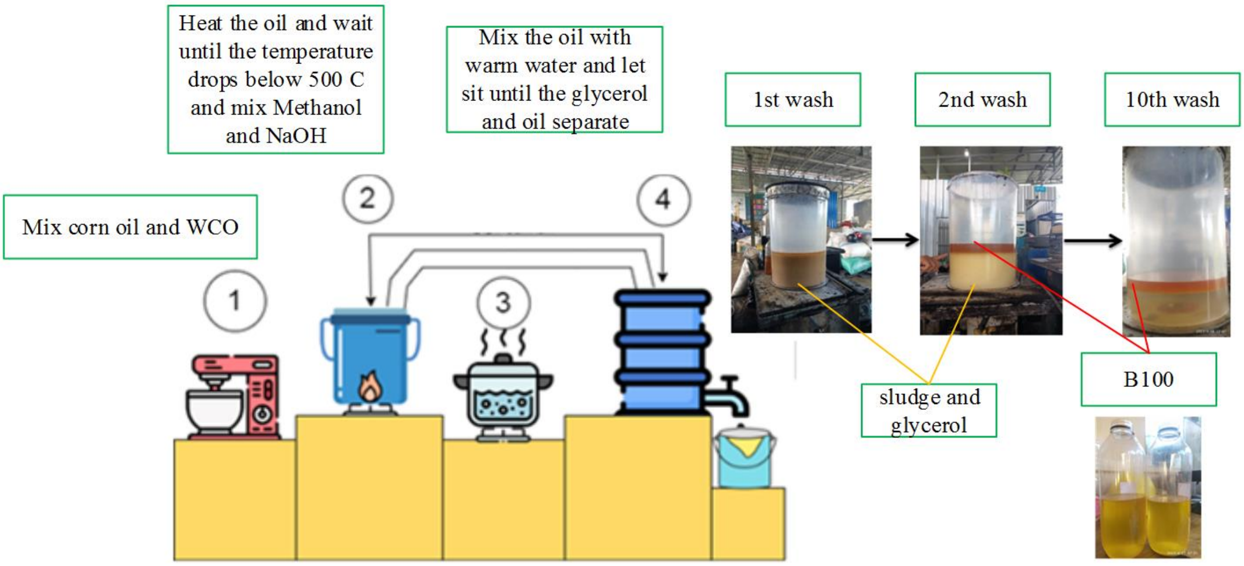

Fig. 1. Biodiesel production process

Following the biodiesel production stage, our study transitions into a critical phase wherein the produced biodiesel is subjected to a battery of rigorous tests conducted on diesel engines. These tests are designed to comprehensively evaluate the performance of engines utilizing a blend of biodiesel and traditional diesel fuel. The parameters under scrutiny encompass a spectrum of vital engine metrics, including but not limited to engine efficiency, fuel consumption, and exhaust emissions generated during the operation of engines employing the biodiesel mixture.

The culminating phase of our research revolves around an in-depth examination of the exhaust emissions stemming from the biodiesel-diesel fuel blend. The central objective of this segment is to elucidate the potential environmental impact of employing this biodiesel-diesel mixture on air quality and the surrounding ecosystem. In this regard, we undertake a comprehensive analysis of various emission types, encompassing exhaust gases and particulate matter, with a keen focus on assessing their ramifications on the environment.

To bolster the credibility of our analysis, we have meticulously gathered the primary data pertinent to the machinery employed in this study, which is presented in Table 1. Additionally, we have provided a schematic representation of our research in Figure 2, offering a visual depiction of the sequential steps encompassed within this investigative endeavor. This diagram serves as a valuable reference for readers seeking a concise overview of our research methodology.

Table 1
Main engine specification

Main Engine	Value	Unit
Engine Model	1 cylinder, 4 Stroke	Vertical
Type	Yanmar, TF 85-MH	
Power	7,5	Kw
Speed max	2200	Rpm
Displacement	493	cc
Compression Ratio	1:18	
Dimension	672x330x496	mm
Weight	87,0	Kg

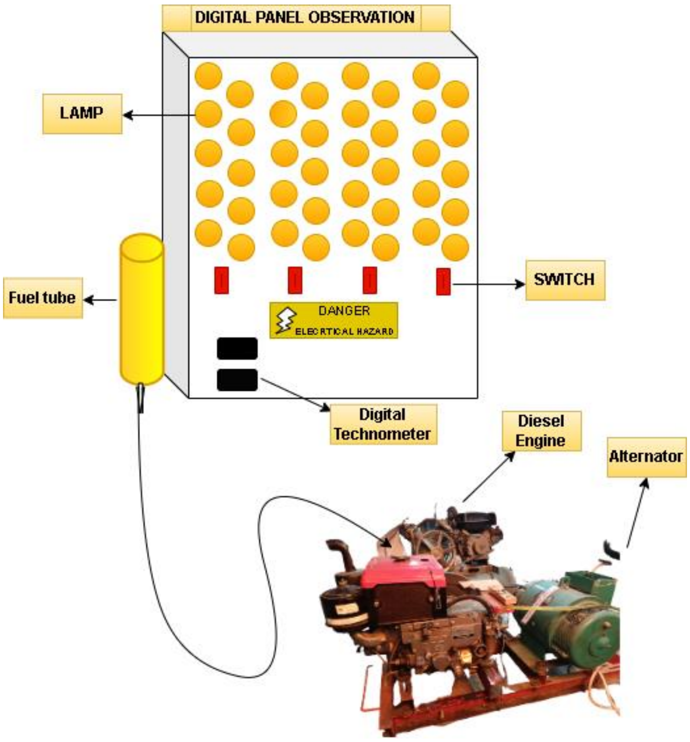

Fig. 2. Testing machine schematic

This research represents a significant and timely contribution to the ongoing endeavors aimed at the development of alternative fuels that are not only environmentally responsible but also efficient. Our utilization of Waste Cooking Oil (WCO) derived from used household frying oil, in conjunction with readily available corn oil, serves as a pioneering step toward both waste reduction and the creation of a fuel blend that holds great promise in terms of mitigating greenhouse gas emissions and air pollution, particularly from vehicles reliant on fossil fuels.

The implications stemming from the outcomes of this research hold substantial weight in the realm of sustainability and the evolution of alternative fuels. The strategic deployment of renewable natural resources, exemplified by corn oil and discarded frying oil, as primary feedstock for biodiesel production underscores the importance of resource efficiency and contributes significantly to curbing the carbon footprint associated with the transportation sector. Furthermore, the reduction in greenhouse gas emissions attributable to biodiesel utilization can substantially bolster global initiatives aimed at combatting climate change.

It is our fervent aspiration that the findings of this research will serve as a solid foundation for further advancements in biodiesel production and adoption, propelling industries toward the embrace of more sustainable technologies. In so doing, this research not only serves to safeguard environmental quality but also actively champions the broader transformation toward a society that is inherently more sustainable in its practices and principles.

Figure 3 represents the 4-stroke diesel engine circuit utilized in this study. The engine is interconnected with a generator to generate electrical current, illustrated by the inclusion of a digital observation panel alongside an incandescent lamp (100 watts).

3. Results

3.1 Fuel Properties

Fuel property testing serves as a critical tool for assessing the compatibility of biodiesel production results with established fuel quality standards. In our investigation, these tests were meticulously conducted on a biodiesel-diesel blend, with each component comprising 50% of the mixture a pivotal composition ensuring the produced biodiesel aligns with specific requirements. The battery of tests encompassed three primary parameters: density, viscosity, and heating value. These parameters hold paramount significance in discerning the quality of biodiesel and verifying its conformance to the applicable quality standards.

The test outcomes have been thoughtfully presented in Figure 3, Figure 4 and Figure 5, providing a visual depiction of the biodiesel's key characteristics (Viscosity, Density, and heating Value). Based on the data presented in the third image, the viscosity and density values of both fuel samples remain within acceptable ranges, complying with established fuel standards. These values fall within the minimum and maximum thresholds as regulated by the government, indicating their feasibility for use. However, in terms of calorific value, the B0 sample exhibits a higher energy content compared to the B50 sample, suggesting a trade-off between energy output and the use of blended fuels. It is imperative to underscore the pivotal role of laboratory testing in the overall process. This phase serves as a linchpin in guaranteeing that the biodiesel meets the stringent quality prerequisites essential for its utilization in vehicles and diesel engines.

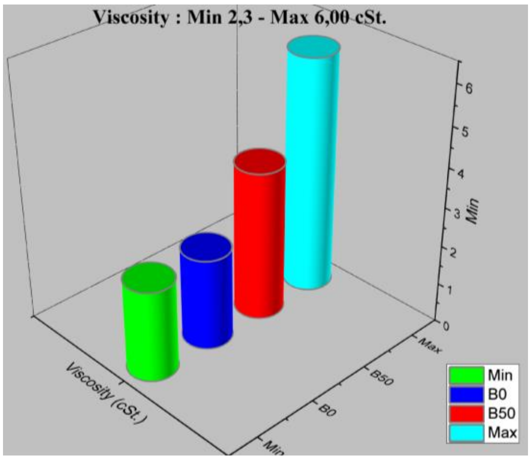

Fig. 3. Viscosity graph

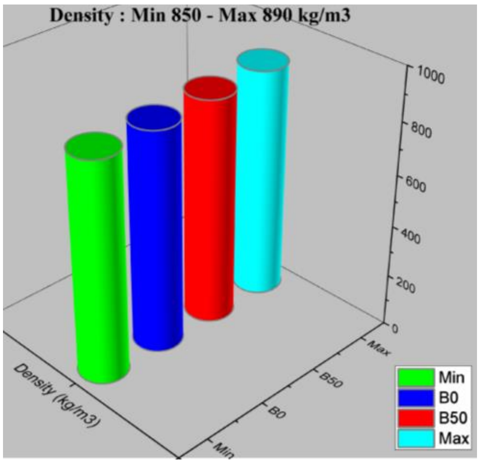

Fig. 4. Density graph

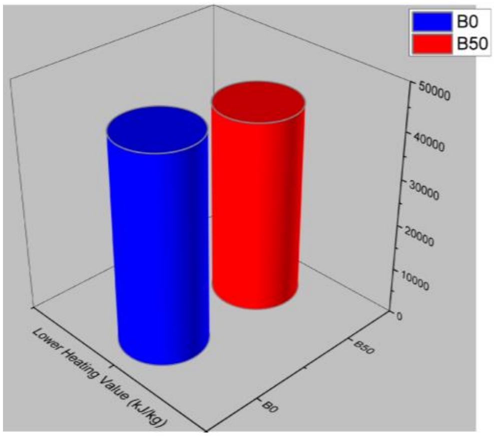

Fig. 5. Heating value graph

3.2 Engine Performance

In this study, comprehensive tests were conducted on diesel engines utilizing the TF 85-MLYS model with a 4-stroke working system. The primary objective was to measure and analyze several crucial performance parameters, including torque, SFC (specific fuel consumption), and thermal efficiency. Our research was geared towards investigating how varying the composition of biodiesel and diesel in the fuel mixture, along with different engine speeds (1000 RPM, 1200 RPM, and 1400 RPM), impacted these key parameters.

The test data collected during these experiments has been subjected to rigorous analysis and is presented graphically for ease of interpretation. The analysis encompasses the following variables 1) torque with load: This parameter quantifies the torque generated by the engine under varying load conditions. It provides insights into the engine's power output at different load levels, helping to gauge its performance under various operational scenarios. 2) SFC with Load: Specific fuel consumption measures the engine's efficiency in utilizing fuel under diverse load conditions. It serves as a vital indicator for assessing the overall fuel efficiency of the engine, offering valuable information on its consumption patterns. 3) Thermal Efficiency with Load: Thermal efficiency gauges the engine's ability to convert the heat generated from fuel combustion into useful mechanical work. This parameter is instrumental in evaluating the energy efficiency of the engine, shedding light on its performance in converting heat into useful output.

Furthermore, the outcomes of the engine tests have been meticulously processed and are presented in Table 2 and Table 3, providing additional detailed insights into engine performance across various rotational conditions. The results obtained from this rigorous analysis will serve as a robust foundation for evaluating the impact of a biodiesel-diesel blend on diesel engine performance. Moreover, it will facilitate an understanding of how variations in engine speed affect these essential performance parameters. This knowledge will contribute significantly to the assessment of biodiesel's suitability as an alternative fuel and its potential influence on engine efficiency and emissions in real-world applications.

Table 2
Pure Diesel Fuel Test Results Data (B0)

Engine Rotation (Rpm)	Load (Watts)	Voltage (Volt)	Current (Ampere)	Time (s)	Amount of Fuel (ml)	Power (kW)
1000	1000	117	3.0	103	10	0.351
	2000	109	5.7	95	10	0.625
	3000	102	8.3	90	10	0.841
	4000	89.2	10.2	83	10	0.909
1200	1000	148	3.4	94	10	0.501
	2000	134	6.4	85	10	0.856
	3000	116	8.9	74	10	1.026
	4000	97.5	10.7	67	10	1.043
1400	1000	179	3.8	78	10	0.671
	2000	160	7.1	62	10	1.129
	3000	127	9.3	59	10	1.181
	4000	90.4	10.7	56	10	0.967

Table 3
Pure Diesel Fuel Test Results Data (B50)

Engine Rotation (Rpm)	Load (Watts)	Voltage (Volt)	Current (Ampere)	Time (s)	Amount of Fuel (ml)	Power (kW)
1000	1000	125	3.09	120	10	0.386
	2000	108	5.76	106	10	0.622
	3000	100	8.23	89	10	0.823
	4000	93.1	10.4	80	10	0.968
1200	1000	145	3.34	99	10	0.484
	2000	133	6.41	83	10	0.852
	3000	117	8.92	69	10	1.043
	4000	97	10.6	65	10	1.028
1400	1000	180	3.78	66	10	0.680
	2000	168	7.34	55	10	1.233
	3000	128	9.38	52	10	1.200
	4000	83.7	9.85	49	10	0.824

In the testing conducted with B50 fuel, which is a blend of biodiesel and diesel fuel, the results reveal interesting variations in fuel consumption times under different engine conditions. Here are the notable findings. 1) Longest Time: The longest duration recorded for depleting the B50 fuel blend occurred at 1000 RPM with a load of 1000 watts. It took a total of 2 minutes and 0 seconds, during which the voltage measured was 125 volts, and the current was 3.09 amperes. 2) Fastest Time: In contrast, the fastest consumption of B50 fuel took place at 1400 RPM with a substantial load of 4000 watts. Remarkably, it only required 49 seconds to exhaust the fuel, with the voltage reading at 83.7 volts and the current at 9.85 amperes.

These findings provide essential insights into the performance characteristics of the B50 fuel blend under varying engine speeds and load conditions. Understanding how this blend performs in terms of fuel consumption is crucial for assessing its suitability as an alternative fuel and its potential impact on engine efficiency and emissions. It also offers valuable information for researchers and engineers looking to optimize the use of B50 fuel in diesel engines.

3.2.1 Comparative analysis of torque B0 and B50

The measurement and comparison of engine torque with pure diesel fuel is vital in assessing engine performance. The torque-load relationship is graphically presented in Figure 4, offering insights into how different fuel samples, including biodiesel blends, influence engine performance.

In Figure 6, which illustrates the torque comparison between B0 and B50 fuels at 1000, Figure 7 illustrate 1200 RPM, and Figure 8 illustrates 1400 RPM variations, notable trends emerge. At 1000 RPM, B50 fuel exhibited the highest torque at 9.25 N·m under a 4000 load, while B0 fuel recorded the lowest torque at 3.35 N·m with a 1000 load. The graph indicates that the difference in torque between B0 and B50 fuels is negligible, and torque increases with higher loads. At 1200 RPM, B0 fuel registered the highest torque at 8.31 N·m under a 4000 load, while B50 fuel displayed the lowest torque at 3.86 N·m with a 1000 load. Similarly, the graph demonstrates an inconsequential difference in torque between B0 and B50 fuels, with torque ascending as load intensifies. At 1400 RPM, B50 fuel achieved the highest torque, reaching 8.42 N·m at a 2000 load, while B0 fuel yielded the lowest torque at 4.58 N·m with a 1000 load. Again, the disparity between B0 and B50 fuels in terms of torque is marginal, and an observable increase in torque occurs with higher loads. These torque comparisons illuminate the consistent performance characteristics of B0 and B50 fuels across different engine speeds and load conditions.

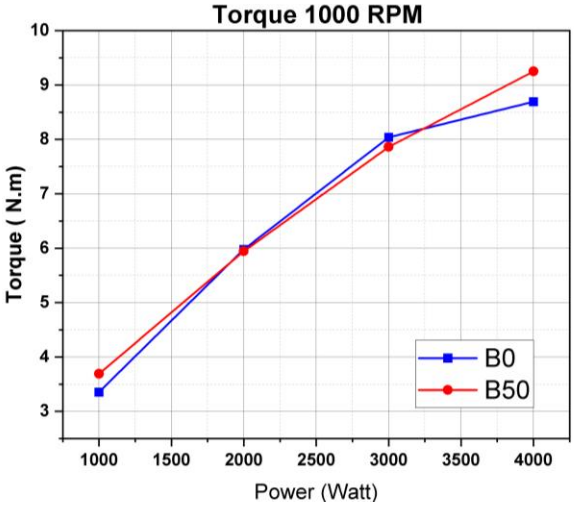

Fig. 6. A torque-load comparison graph at 1000 Rpm

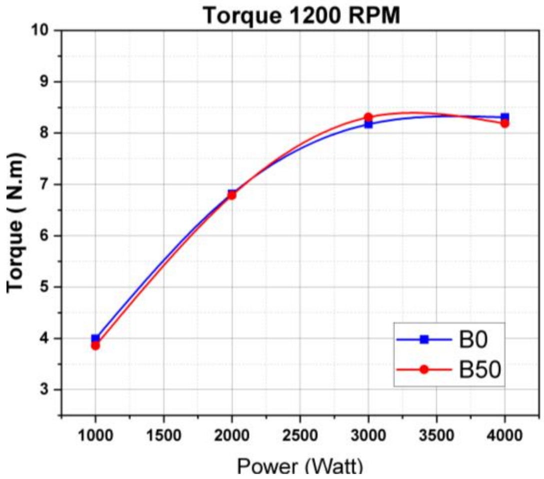

Fig. 7. A torque-load comparison (1200 Rpm)

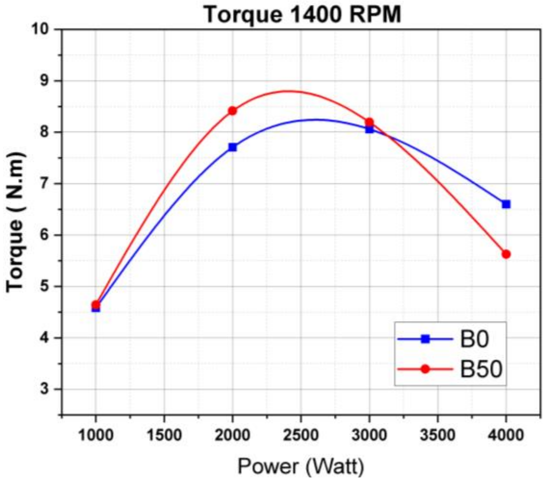

Fig. 8. A torque-load comparison (1400 Rpm)

3.2.2 Comparative analysis of SFC B0 and B50

Figure 9, Figure 10, and Figure 11 (SFC vs. Load, RPM 1000), it is evident that B50 fuel exhibits a lower SFC (Specific Fuel Consumption) value at 1000 RPM compared to B0 fuel. Specifically, B50 fuel records an SFC of 405.736 gr/kWh, while B0 fuel displays a higher SFC value of 852.377 gr/kWh, particularly at a light load of 1000. This discrepancy signifies that B50 fuel is more fuel-efficient in this context. The lower SFC observed in B50 fuel can be attributed to the shorter fuel test times experienced at higher loads, leading to a reduction in SFC values for B50. This suggests that B50 fuel offers improved fuel consumption efficiency compared to B0 fuel, particularly at the specified conditions.

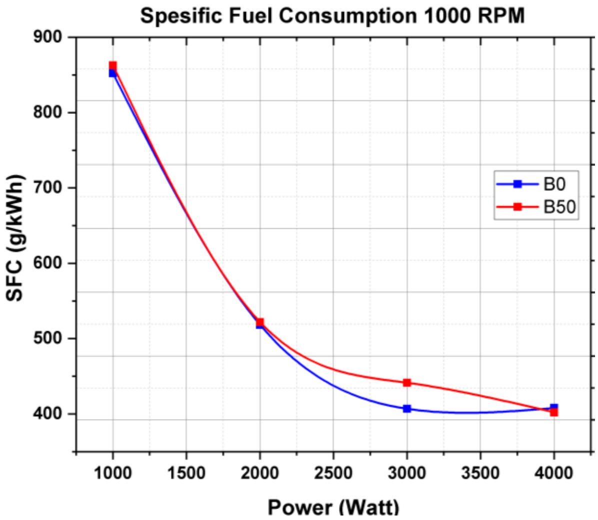

Fig. 9. An SFC-load comparison graph at 1000 Rpm

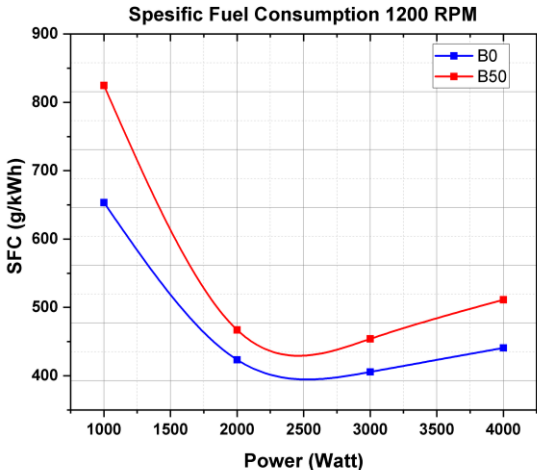

Fig. 10. An SFC-load comparison (1200 Rpm)

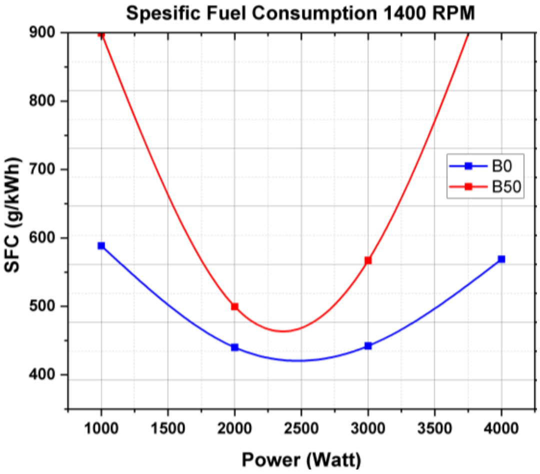

Fig. 11. An SFC-load comparison (1400 Rpm)

At 1200 RPM, a notable disparity in SFC (Specific Fuel Consumption) between B0 and B50 fuels is observed. B50 fuel exhibits the lowest SFC (655.492 gr/kWh) under a light load of 1000, while B0 fuel demonstrates the highest SFC (405.642 gr/kWh) with a light load of 3000. This variance is influenced by power (watts) and fuel flow rate (mf), both of which are contingent on the diesel engine's test duration and the light load. Lower lamp loads result in extended test times and higher SFC, indicating elevated fuel consumption. Conversely, higher lamp loads lead to shorter test durations and lower SFC, signifying more efficient fuel utilization.

At 1400 RPM, the discrepancy in SFC between B0 and B50 fuels remains evident. B50 fuel records the highest SFC (777.963 gr/kWh) under a light load of 4000, while B0 fuel registers the lowest SFC (440.007 gr/kWh) with a light load of 2000. These results continue to be influenced by power and fuel flow rate, which mirror the test duration and light load. This distinction highlights that B50 exhibits inferior performance compared to B0 at the 1400 RPM variation.

3.2.3 Comparative analysis of thermal efficiency B0 and B50

Figure 12, Figure 13, and Figure 14 display the thermal efficiency against load at 1000 RPM for both B0 and B50 fuels. The thermal efficiency of the fuel is greatly influenced by the power (watts), mf value (potential energy containing the fuel flow rate), fuel heating value (LHV), and time. It is noted that higher fuel calorific value, power (watts), and mf value lead to increased thermal efficiency. This occurs because the load size significantly impacts the resulting thermal efficiency, resulting in reduced combustion at higher loads.

Conversely, lower values of power (watts) and mf, combined with lower lamp loads, yield decreased thermal efficiency, indicating more significant combustion. The graph demonstrates that the highest value is achieved with B50 fuel, reaching 22% at 1000 RPM and a load of 4000 watts, while the lowest value is observed in the B0 fuel graph at 1000 RPM and a load of 1000 watts, with a thermal efficiency of 10%.

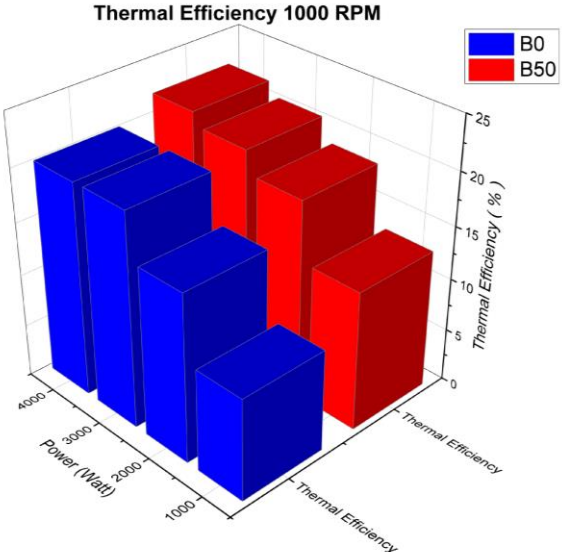

Fig. 12. Thermal Efficiency-load comparison graph at 1000 Rpm

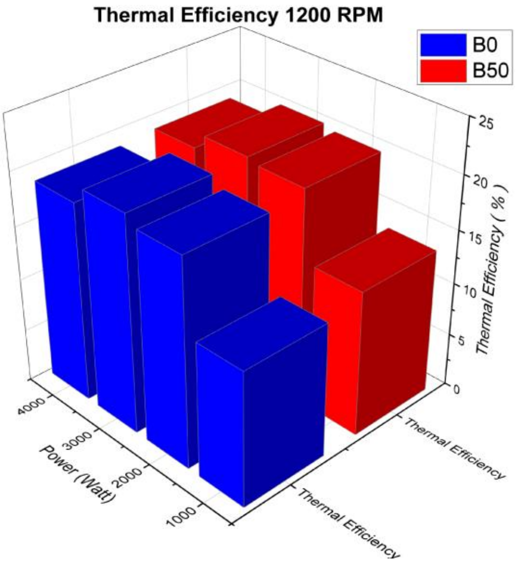

Fig. 13. Thermal Efficiency-load comparison (1200 Rpm)

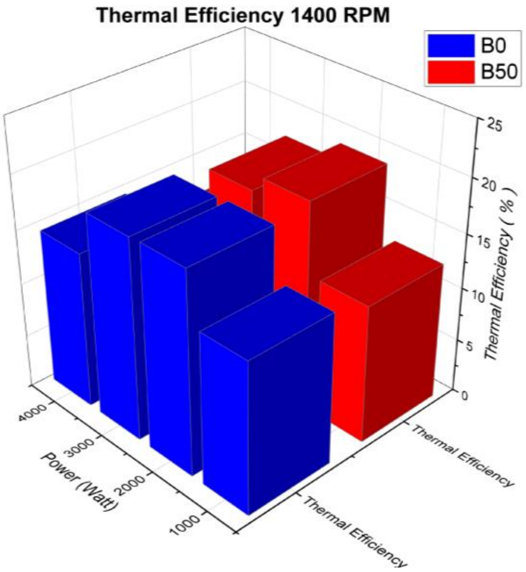

Fig. 14. Thermal Efficiency-load comparison (1400 Rpm)

At 1200 RPM, thermal efficiency significantly depends on power (watts), fuel flow rate (mf), fuel heating value (LHV), and time. Efficiency improves with higher calorific value, power, and mf, indicating enhanced combustion. Conversely, reduced power, mf, and lamp load result in lower efficiency. B50 fuel exhibits the highest efficiency at 20%, while B0 fuel records the lowest at 13%.

At 1400 RPM, thermal efficiency is similarly influenced by power (watts), mf, LHV, and time. Efficiency rises with increased calorific value, power, and mf. Lower efficiency is associated with reduced power, mf, and lamp load. B0 fuel achieves the highest efficiency at 19%, whereas B50 fuel has the lowest at 11%.

3.2.4 Exhaust emission

Exhaust gas emission testing in biodiesel research focuses on quantifying smoke density levels generated by diesel engines. Table 4 herein offers a comprehensive juxtaposition of emission test outcomes for B0 and B50 fuels. These findings offer pertinent insights into the influence of these fuels on exhaust emissions. This information holds significance in the quest to enhance the efficiency and sustainability of alternative fuels.

Table 4
Comparison of Emission Test

Sample	Density (N)%	Oli Temperature	Coefficient
B0	98.3	80	3.73
B50	80.5	78	3.80

The opacity test results presented in the table above reveal significant disparities between diesel fuel and B50 fuel. Diesel fuel exhibits a markedly higher density level, reaching 98.3%, at an oil temperature of 80 degrees Celsius, accompanied by a coefficient value of 3.73. In contrast, B50 fuel demonstrates a lower concentration level, approximately 80.5%, with an oil temperature of 78 degrees Celsius and a coefficient value of 3.80. These findings underscore that the exhaust gas concentration test for diesel fuel reveals a higher and more concentrated emission content. Such emissions have the potential to contribute to environmental pollution and elevate air pollution levels on roadways.

4. Conclusions

The biodiesel production process, involving a blend of corn oil and used cooking oil, comprises distinct stages: oil mixing, catalyst liquid preparation with methanol and NaOH, heating to 90°C for mixing with the catalyst, a 24-hour cooling phase for glycerol and biodiesel separation, and final washing with heated water in a 1:1 ratio. Performance tests on diesel engines using B0 and B50 fuels reveal notable distinctions. B50 consistently outperforms B0, displaying higher torque, improved fuel efficiency (lower SFC values), and increased thermal efficiency. Moreover, B50 exhibits lower exhaust emissions. These findings underscore the positive impact of biodiesel addition on engine performance, emphasizing increased torque, enhanced fuel efficiency, and reduced emissions, influenced by biodiesel characteristics.

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